Application of indicators based on regional climate model results

Report summary

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Content

Introduction

To have targeted and sustainable adaptation strategies, detailed and quantitative information on regional climate change and its local impacts is of key importance. The National Adaptation Geographical Information System (NAGiS) has been established in 2013 to support strategic planning and decision making related to the adaptation in Hungary. To define the proper adaptation actions, scientific credibility of the information system has great importance. The most essential input of NAGiS is served by climate data, i.e., observations and future projections. In Hungary, four different regional climate models (RCMs) have been adapted and used for analysing future climate change in detail (Bartholy et al., 2011). Among them, two RCMs are used to provide projected climate information for the users of NAGIS: ALADIN-Climate (Csima és Horányi, 2008) and RegCM (Torma, 2011; Torma et al., 2011) models adapted by the Hungarian Meteorological Service and the Department of Meteorology of the Eötvös Loránd University, respectively. Although the basic governing equations are identical in the two RCMs, different approaches and parametrization schemes are applied. Moreover, the lateral boundary conditions are provided by different global climate models (GCMs) to the regional experiments. These structural differences lead to different results, thus, enabling us to assess the uncertainties of regional climate projections at a certain level. The combined evaluation of an ensemble of RCM simulations is required in objective and correct impact studies, which is an important aim of the NAGiS initiative.

Present paper is dedicated to introduce the scientific background of climate change investigations and give a comprehensive assessment of climate model data included in NAGiS, in order to support proper application and interpretation of RCM results. In chapter 2, description of climate system and its numerical modelling is given, with special focus on regional climate modelling. This part of the document discusses the sources of uncertainties in climate projections as well as international co-operations aiming at assessment of global to regional climate change and related uncertainties. Chapter 3 deals with milestones of climate dynamics activities and steps done in adaptation to climate change impacts in Hungary. In chapter 4, an overview is provided about the climate information available in NAGiS; ALADIN and RegCM results are analysed in detail. The most important conclusions are drawn in chapter 5, and the paper is closed by an outlook with critical evaluation of credibility and user practice of NAGiS climate information, and with raising some development issues.

Model simulations

Climate change simulations of ALADIN and RegCM were achieved over the Carpathian Basin on 10 km horizontal resolution, prescribing anthropogenic activity according to the intermediate SRES A1B emission scenario (Nakicenovic et al., 2000). First, RCM outputs are validated against gridded observational datasets of CRU (Mitchell et al., 2004) and CARPATCLIM (Lakatos et al., 2013) for the reference period of 1961–1990. Afterwards, future projections are evaluated concentrating on two periods: 2021–2050 for adaptation to climate change on decadal time scale and 2071–2100 for long-term strategic planning. The investigations are focuses on daily, monthly, seasonal and annual mean temperature and precipitation. In the case of future projections, uncertainties of the estimations are also quantified, which are originated primarily from the differences of driving GCMs and driven RCMs.

Validation

Validation of simulation results is an important issue in the interpretation of RCM-based climate projections. In this process it is evaluated how well the past climatic conditions are reproduced by the model simulations. Although validation is a highly important and strictly required step in any modelling approach, there is no guarantee that models with good performance for the past will provide reasonable future climate estimations, as well. The validation analysis of the simulation results of the two RCMs available in NAGiS shows that:

- ALADIN-Climate significantly underestimates the spring and autumn temperature conditions, whereas overestimation is found in summer. In case of RegCM, winter temperature is overestimated, which is compensated on annual scale by the smaller underestimations in the other three seasons. Considering the extreme temperature conditions, ALADIN-Climate is slightly overestimating both the warm and the cold related climatic indices, whereas RegCM underestimates them.
- In general, simulations of both RCMs result in larger annual precipitation totals than measured during the reference period in the country. The annual cycle of monthly mean precipitation amounts is better reproduced by ALADIN-Climate, although precipitation totals in May-June-July are highly overestimated. In case of RegCM the simulated monthly mean precipitation amounts are very similar to each other, thus the annual cycle is relatively poorly reproduced. The RCMs provide generally better estimations for the precipitation-related than the temperature-related indices.

Future projections

Both past observations and available information for the future based on RCM results show that mean temperature do and will increase over Hungary. This change is statistically significant for each period by the two models, which means that the rate of changes exceed the natural variability. The RCM results for mean temperature can be summarized as follows:

- Annual mean temperature change is about 1-2°C for 2021–2050 and 3-5°C by the end of the century over Hungary (**Table 1**), thus temperature will likely to increase successively during the 21st century (even though also cooler years and seasons will occur due to natural variability).
- By the mid-century, spring and winter mean temperature is likely to increase between 1°C and 2°C over Hungary in the next decades and approach 3°C by the end of century according to both simulations. Larger warming is projected in the eastern and southern parts of Hungary. The uncertainty in model outcomes is much higher in summer and autumn: according to one of the projections the warming is less than 1°C until near future, while the other model indicates 2-3°C increase (**Table 1**). Summer temperature rise in far future will be between 3°C and 5°C, or even higher, for instance in August it may exceed 6°C (**Fig. 1**).

Table 1. Annual and seasonal mean temperature changes (°C) over Hungary for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models.

	Annual	Spring	Summer	Autumn	Winter
2021–2050	1.1–1.9	1.6	0.7–2.6	0.8–2.0	1.1–1.3
2071–2100	3.1–3.5	2.8–3.1	3.5–4.9	3.0–3.6	2.5–2.9

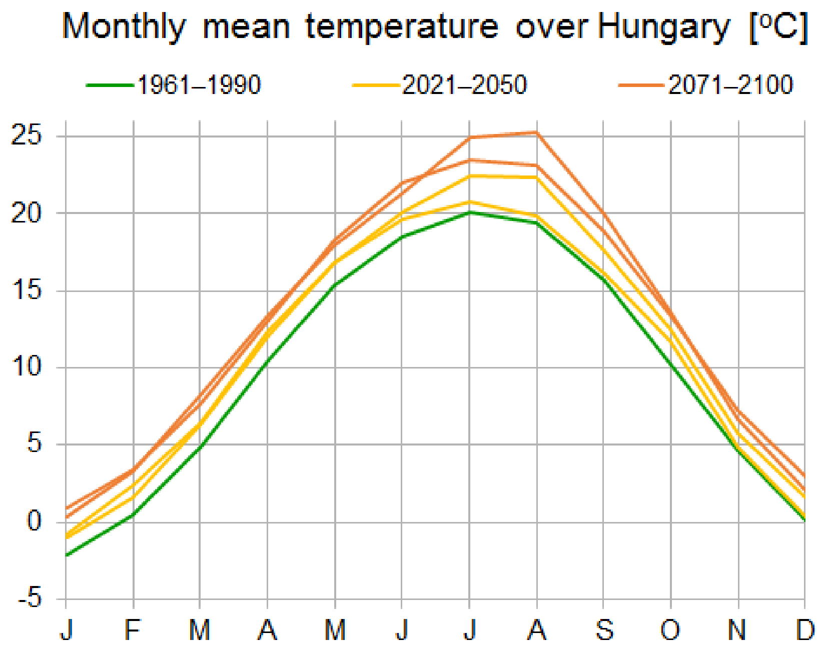

Fig. 1. Monthly mean temperature values (°C) over Hungary for 1961–1990 based on observations, for 2021–2050 and 2071–2100 based on results of ALADIN-Climate and RegCM regional climate models. Future values are calculated as sum of observation values in the reference period and projected changes.

Monthly, seasonal and annual temperature tendencies naturally imply changes in the daily temperature values. Frequency distributions (**Fig. 2**), are investigated for two months: January and July are the coldest and the warmest months in Hungary. In addition, four temperature indices were also investigated: extremely cold day, frost day, summer day and hot day (**Table 2**). Their changes are given in days for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990. The intervals in **Table 2** mean the minimum and maximum changes averaged over Hungary based on the two RCMs. Main conclusions are as follows:

- A clear shift can be observed towards higher temperatures both in January and July (**Fig. 2**). In January, the occurrences of daily mean temperature values below 0°C clearly reduce while the ones belonging to temperatures above 4°C increase. At the end of the century, the most frequent daily temperature values will be above freezing point according to both projections. This shift is even more prominent in July, when daily mean values can grow with 5-6°C and the relative frequency of days with extremely high values is also strongly enhanced.

- As expected, the number of warm extremes, like summer days and hot days is projected to increase significantly, while cold extremes such as frost days and extremely cold days tend to become less frequent. However, the projected actual mean changes are somewhat different due to the fact that the RCMs reproduce differently the occurrences of the extremes in the reference period.

- While 66 summer days were observed in Hungary during 1961–1990, the projected increase will be 4-21 days until 2021–2050, and 28-40 days by the end of the century. In case of hot days, the expected change is 2-24 days for the near future, and 8-49 days for the far future (**Table 2**).

- At the same time, contrary to the warm extremes, a strong reduction is foreseen in the occurrence of cold indices: the number of frost days will likely decrease from 96 days with about one month, while the frequency of extremely cold days may be reduced by half at the end of the century (**Table 2**)

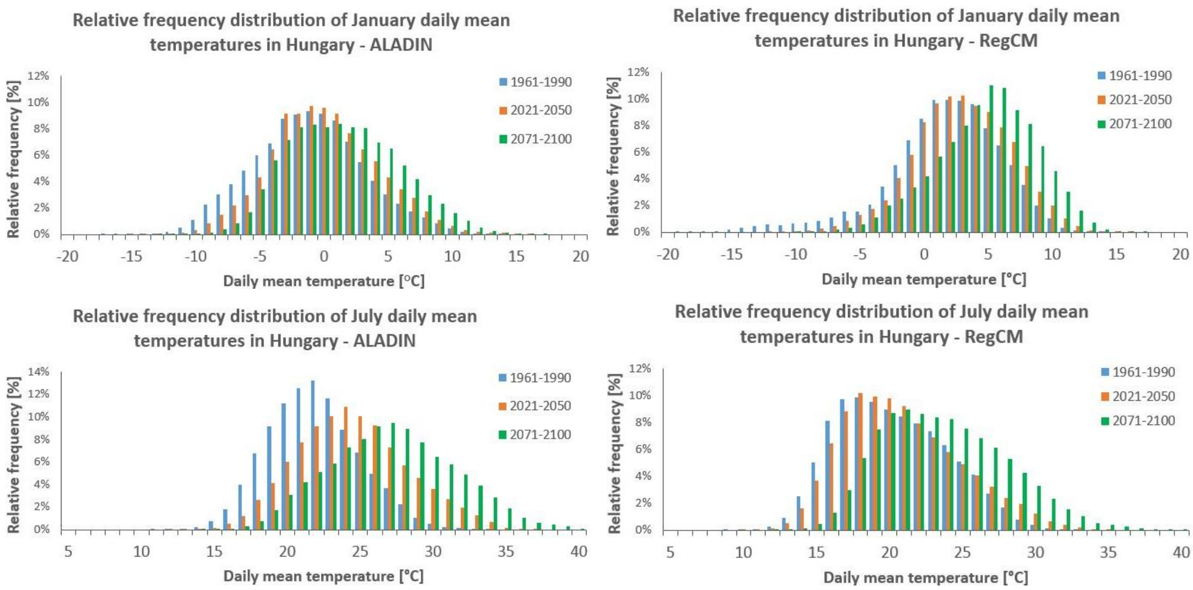

Fig. 2. Relative frequency of January (top) and July (bottom) daily mean temperature values (%) in gridpoints over Hungary for 1961–1990, 2021–2050 and 2071–2100 based on results of ALADIN-Climate (left) and RegCM (right) regional climate models.

Table 2. Mean annual change of temperature indices (day) over Hungary for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models.

Index	2021–2050	2071–2100
Summer day: daily maximum temperature > 25°C	4–21	28–40
Hot day: daily maximum temperature > 30°C	1.7–24	8–49
Frost day: daily minimum temperature < 0°C	(-23) – (-9)	(-41) – (-25)
Extremely cold day: daily minimum temperature < -10°C	(-5) – (-1.3)	(-7) – (-1.5)

Estimation of future precipitation change in the Carpathian Basin is extremely ambiguous, since it is located between northern and southern regions, where projections available in Europe indicate precipitation increase and decrease, respectively. Different models often project different sign of changes, what is more these changes are not even significant in every season and gridpoint. Precipitation has heavy fluctuation in space and time, therefore, changes are presented in relative form, compared to the model results for a past period, which was 1961–1990 in our case:

- During the 21st century, on annual average only small (below 10%) precipitation decrease is expected in Hungary (**Table 3**), however, on southwestern part of the country stronger, significant decrease may occur according to one of the RCMs.
- The seasonal variability is projected to slightly change mainly due to the clear drying tendency in summer as the highest mean precipitation was observed in this season in the reference period (**Fig. 3**). The degree of this change is below 5% in the near future, however, by 2071–2100 it will deepen largely, approximately 20% less precipitation may fall on average.

- Based on our model set, winter in the next decades is also clearly exposed to less precipitation with 10% that exceeds the summer changes. In the far future, the direction of changes is uncertain, since decrease turns into increase in one of the models.
- Regarding the transient seasons, only autumn precipitation change at the end of the century is obvious. Both models project considerable increase (on spatial average up to 10%). Based on observed climatology, there is a secondary maximum in November. This seems to be modified in the far-future: November amounts may approximate the June values, according to one of the models.

Table 3. Annual and seasonal mean precipitation changes (%) over Hungary for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models. Changes with same direction is highlighted with brown (decrease) and green (increase) colours.

	Annual	Spring	Summer	Autumn	Winter
2021–2050	(-7) – (-0.2)	(-10) – 3.4	(-5) – (-2.1)	(-3.8) – 14	-10
2071–2100	(-5) – (-2.3)	(-5) – 2.1	(-20) – (-18)	4.6 – 10	(-3.1) – 8

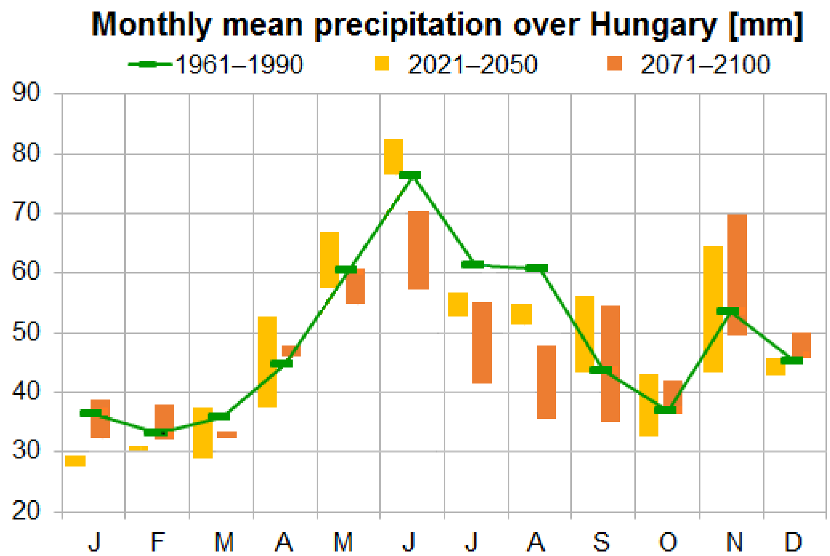

Fig. 3. Monthly mean precipitation amounts (mm) over Hungary for 1961–1990 based on observations, for 2021–2050 and 2071–2100 based on results of ALADIN-Climate and RegCM regional climate models. Future values are calculated from observation reference values multiplied by projected changes.

Changes in daily precipitation are also investigated through derived climate indices. Some of them count the days when the daily amounts exceed a certain threshold (1 mm, 10 mm, 20 mm). Moreover, we also calculated the precipitation intensity i.e., the fraction of precipitation sum and days when precipitation is above 1 mm, and maximum length of dry spells, which is the longest precipitation-free period when the daily sum is less than 1 mm.

- In the 21st century, fewer days with precipitation are expected in every season, except for spring in 2021–2050, when the direction of changes is uncertain (**Table 4**). At the same time, one may face with more frequent heavy precipitation events by the end of the century, except for summer. The largest increase is projected in autumn and winter.

- Changes in precipitation intensity follow the abovementioned tendencies, however, since the winter precipitation increase is only small, it causes slight enhancement in intensity, as well. Not like autumn, when above 10% change is projected in the majority of gridpoints and is significant in greater extent, according to one of the models (**Fig. 4**). It has to be mentioned, that measurements of past decades revealed the largest precipitation intensity increase in summer, underlining the non-linear character of the climate system.
- In future, Hungary may be exposed to longer dry periods. The highest increase is projected in summer (**Fig. 5**) and autumn in 2071–2100; according to one of the models, summer changes are significant in every gridpoint and may exceed 60% in the Southeast.

Table 4. Mean seasonal changes of precipitation indices (%) over Hungary for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models. Changes with same direction is highlighted with brown (decrease) and green (increase) colours.

Index		2021–2050	2071–2100
Precipitation day: daily precipitation > 1 mm	spring	(-13) – 0.9	(-14) – (-6)
	summer	-8	(-25) – (-23)
	autumn	(-10) – (-0.8)	(-12) – (-9)
	winter	(-15) – (-11)	-7
Heavy precipitation day: daily precipitation > 10 mm	spring	(-6) – 4.9	3.6–4.9
	summer	(-6) – (-1)	(-19) – (-12)
	autumn	(-3) – 25	12–30
	winter	(-15) – (-3)	10–25
Extremely heavy precipitation day: daily precipitation > 20 mm	spring	9–11	37–38
	summer	14–19	(-0.3) – 2.1
	autumn	10–56	39–68
	winter	(-3.9) – (-1)	31–63
Precipitation intensity: precipitation / number of days with precipitation > 1mm	spring	0.1–4.1	3.7–9
	summer	-3.4–7	(-8) – 8
	autumn	7– 18	12–20
	winter	(-1.1) – 4.5	5.4–13
Maximum length of dry periods: consecutive dry days with precipitation < 1mm	spring	(-16) – 14	1.9–14
	summer	3.7–9	19–47
	autumn	0.9–7	16–19
	winter	6.2–11	7.5–11

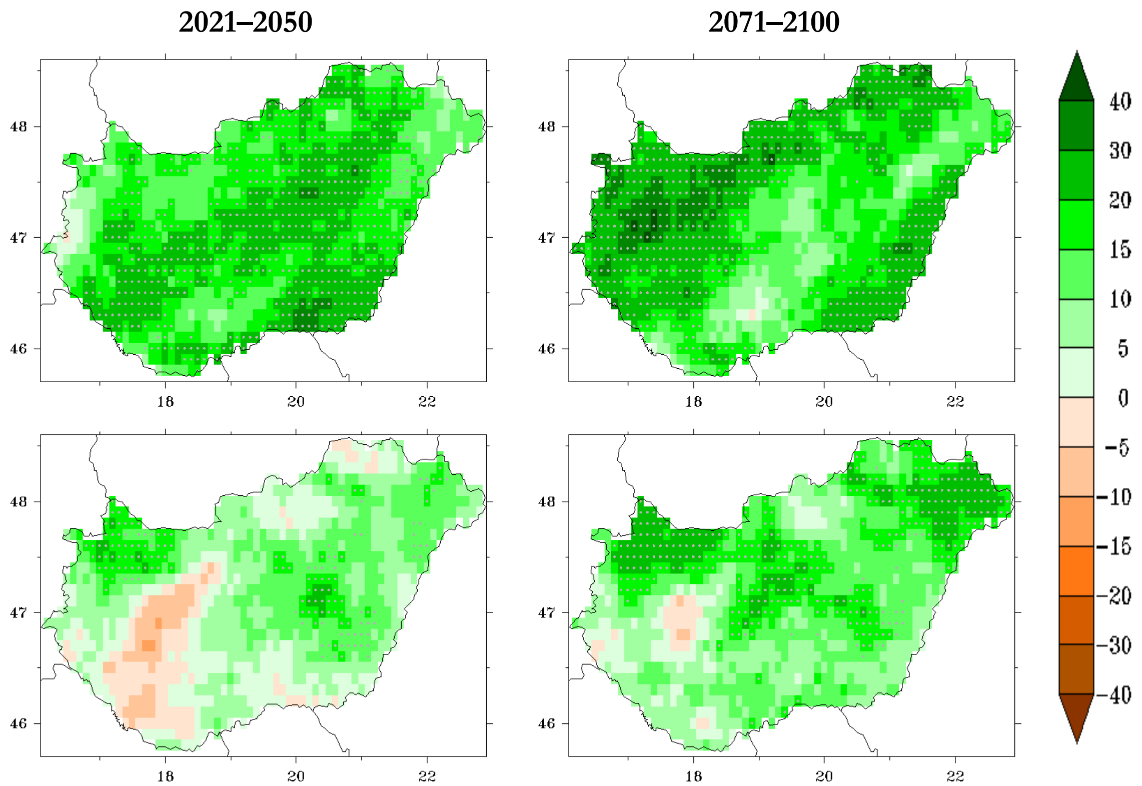

Fig. 4. Mean change of autumn precipitation intensity (%) for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models. Grey dots represent significant changes.

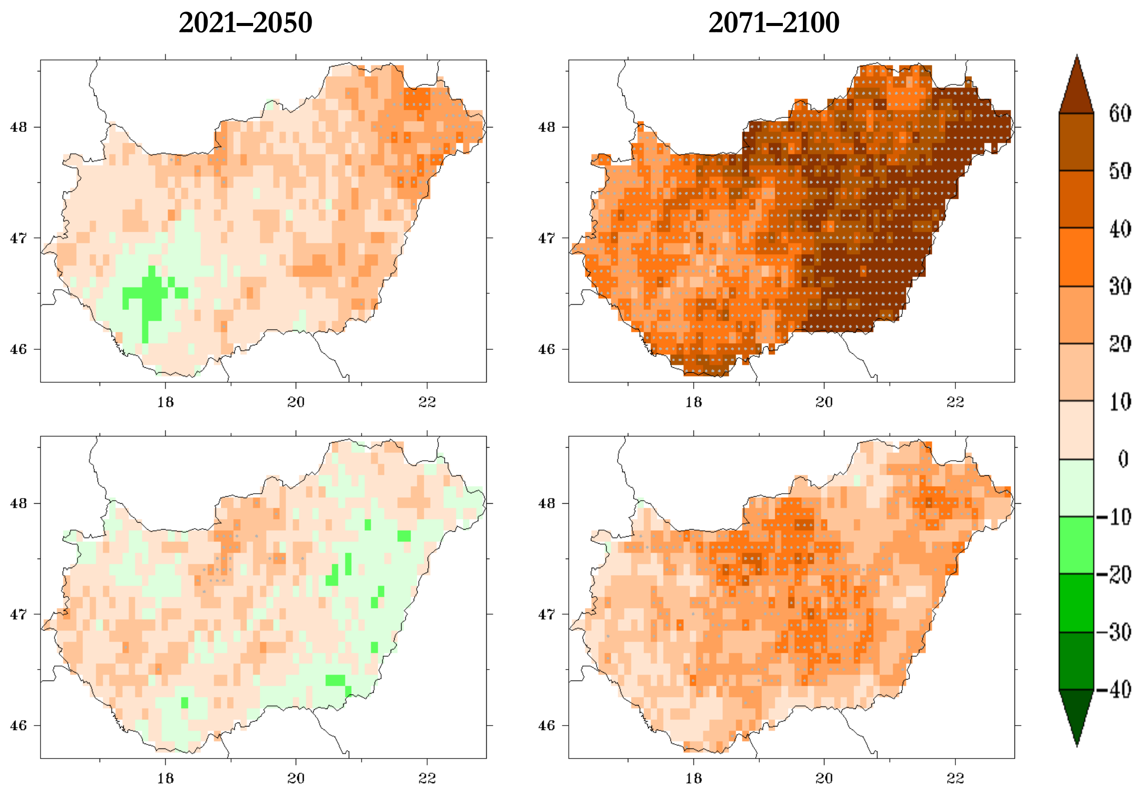

Fig. 5. Mean change in maximum length of summer dry periods (%) for 2021–2050 and 2071–2100 with respect to the reference period of 1961–1990 based on results of ALADIN-Climate and RegCM regional climate models. Grey dots represent significant changes.

Outlook

The climate projection information available in NAGiS provides reasonable basis for objective impact assessments. Nevertheless, further developments are needed which are concisely summarized below:

1. Climate information of NAGiS provides appropriate input data for impact and vulnerability studies, e.g., on agriculture, ecology, tourism, human health, road accidents, Lake Balaton. However, the data cannot be applied in transboundary investigations, most critically in hydrological analyses (Szépszó et al., 2014). In addition, temporal and horizontal resolution of the model outputs are not sufficient for certain case studies. All that suggests that even though NAGiS is maintained by Geological and Geophysical Institute of Hungary and National Adaptation Centre (MFGI/NAK), **climate data provision for NAGiS should be official task of Hungarian Meteorological Service and its financial support has to be ensured by the Hungarian government**.
2. A 2-member ensemble provides moderate information about uncertainties of future climate projections in Hungary. However, **an optimal ensemble should consist of at least 8-10 RCM simulations chosen carefully. In order to establish an efficient and scientifically sound ensemble system, consultation is needed with climate modelling practitioners.**
3. Serious problem is that current users of NAGiS usually neglect one of the two available climate simulations. This single model ("deterministic") approach is not correct, especially in climate studies, moreover, it is in contradiction with original objectives of NAGiS. **It is proposed to provide probabilistic information (besides, or optimally, instead of individual time series) for the users in order to orientate them towards taking the uncertainty into account and avoid the arbitrary selection among the model data.**
4. According to recent experiences, users cooperate only with colleagues at MFGI/NAK, but do not consult with climate modelling practitioners at all. Due to this fact, they are not aware of the proper way for application and interpretation of model data, consequently, they often utilize climate projection data in inappropriate way. **To overcome this problem, direct consultation and dialogue are desired between the impact community and climate modellers; furthermore, that should be required as precondition for using the data.**

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